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# A Low-Complexity SLM PAPR Reduction Scheme for OFDMA

**P. Raveen[1]*, U.V. Ratna Kumari[1]**

[1]Department of Electronics and Communication Engineering, Jawaharlal Nehru Technology University, Kakinada, INDIA

*Corresponding Author

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**Abstract:** In orthogonal frequency division multiplexing (OFDM) systems, selected mapping (SLM) techniques are widely used to minimize the peak to average power ratio (PAPR). The candidate signals are generated in the time domain by linearly mixing the original time-domain transmitted signal with numerous cyclic shift equivalents to reduce the amount of Inverse Fast Fourier Transform (IFFT) operations in typical SLM systems. The weighting factors and number of cyclic shifts, on the other hand, should be carefully chosen to guarantee that the elements of the appropriate frequency domain phase rotation vectors are of equal magnitude. A low-complexity expression is chosen from among these options to create the proposed low-complexity scheme, which only requires one IFFT. In comparison to the existing SLM technique, the new SLM scheme achieves equivalent PAPR reduction performance with significantly less computing complexity. MATLAB tool is used for simulating the proposed work.

**Keywords:** Selective Level Mapping (SLM), Inter Carrier Interference (ICI), Multi Carrier Modulation (MCM), Inverse Fast Fourier Transform, Cyclic Prefix (CP), Inter Symbol Interference (ISI), Peak to Average Power Ratio (PAPR)

## 1. Introduction

ORTHOGONAL frequency division multiple access (OFDMA) systems have risen to prominence as the chosen design for broadband wireless networks like WiMAX (worldwide interoperability for microwave access) networks [1]. In OFDMA systems, sub-carriers are assigned to different users for simultaneous transmission, with the caveat that no sub-carrier can be held by more than one user at the same time. OFDMA systems feature all of the advantages of orthogonal frequency division multiplexing (OFDM) systems, including high spectral efficiency and resistance to multi-path channel interference. On the other hand, traditional OFDM systems have a high peak-to-average power ratio, which OFDMA inherits (PAPR). Some of the PAPR reduction solutions established for OFDM systems in recent years include clipping [2-4], coding, selective mapping (SLM) [5-14], partial transmit sequence (PTS) [15-17], active constellation extension (ACE) [18]-[19], and tone reservation [20]-[21]. Despite their ubiquitous use, SLM techniques require a bank of inverse fast Fourier transforms (IFFTs) to generate candidate signals. The authors in [10-14] have offered a number of ways for reducing computational complexity. However, the approaches presented in [10] and [11] still necessitate at least two IFFT operations. In this paper's suggested low-complexity SLM architecture, which requires only one IFFT, the conversion vectors acquired by applying the IFFT of the phase rotation vectors are used in place of the normal IFFT operations.

PAPR and computational complexity are key issues in OFDMA systems, especially for mobile terminals. As a result of this work, a straightforward method for PAPR reduction in OFDMA systems with only one IFFT is now available. The suggested approach generates candidate signals in the time domain for each user, which are simply a

*Corresponding author: raveen321@gmail.com

linear combination of the original time domain transmitted signal plus multiple cyclic shift equivalents. To ensure that the signal intensities of the individual sub-carriers have the same gain, the elements of the corresponding phase rotation vectors for the sub-carriers assigned to a specific user should have the same magnitude [22-25]. As a result, the number of cyclic shifts and weighting coefficients must be carefully chosen rather than chosen at random.

The equal-gain-magnitude condition of the sub-carrier assignment structure is satisfied by numerous equations in this work. The proposed architecture is implemented using a low-complexity method that has been shown to work in OFDMA systems with any positive integer power of two for the number of sub-carrier groups. As a result, the suggested technique allows an OFDMA system to have several configurations using a single implementation. The PAPR reduction performance of the proposed strategy is comparable to that of the existing SLM approach. On the other hand, the proposed method has a substantially reduced computational complexity.

The remainder of this paper is organized as follows. Section 2 describes the Peak to average power ratio, whereas section 3 describes the proposed low complexity method. The computational complexity of the suggested architecture is addressed in section 4. In section 5, the simulation results are reported. Section 6 comes to a close with a few closing remarks.

## 2. Peak to Average Power Ratio (PAPR)

## 2.1 PAPR in Non-OFDM or Single Carrier System

Consider a single carrier system, which is modulated with BPSK modulated symbols is shown in fig 1.

x(0) x (1) x (2) ....

+a -a +a ....

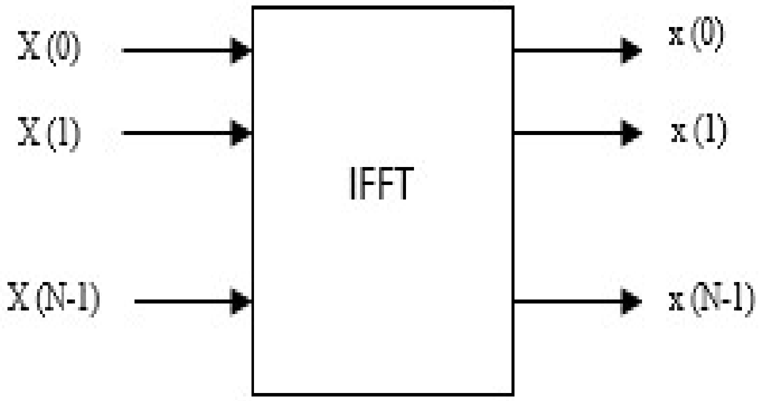


**Fig. 1 - IFFT conversion**

Power in each symbol = Peak Power = a2
Average Power = E $|x(k)|$2= a2
Therefore, in this single carrier system, both Peak and Average Power = a2
PAPR = Peak Power/Average Power = 1 = 0dB
Hence, there is no considerable deviation from the mean power level [3].

## 2.2 PAPR in OFDM System

Information symbols X (0), X (1), X (2) .... +/- a, +/- a, +/- a These information symbols are loaded onto sub carriers.

Hence, the transmitted samples are x (0), x (1) ... x(n-1), which are IFFT samples of information symbols X (0), X (1) ...X(N-1).

$K^{th}$ IFFT sample x(k) = I/N$\sum_{i=0}^{N-1} X(i) e^{j2\pi ki/N}$
Average Power = E$\{|x(k)|^2\}$
= $1/N^2 \sum_{i=0}^{N-1} E\{square\ of\ |X(i)|\} E\{e^{\frac{j2\pi ki}{N}}\}^2$
= $1/N^2 \sum_{i=0}^{N-1} E\{sqauare\ of\ (X\{i)\}$

$= 1/N^2\sum_{i=0}^{N-1} a^2$
$= 1/N^{2*}a^2N$
$= a^2/N$
Hence, the average power of transmission is $a^2/N$.
Peak Power = $x(0)^2$
$X(0) = \frac{1}{N}\sum_{i=0}^{N-1} X(i)e^{j2\pi(0)i/N}$
$= \frac{1}{N}\sum_{i=0}^{N-1} X(i)$
X (0) = X (1) = X (2) =………= X(N-1) = +a
$X(0) = \frac{1}{N}\sum_{i=0}^{N-1} X(i)$
$= \frac{1}{N}\sum_{i=0}^{N-1} a$
= a
Peak Power = $a^2$
Hence Peak to Average Power Ratio is
PAPR = a2/a2/N = N.

**Table 1 - PAPR of OFDM**

| No of Sub carriers(N) | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|
| PAPR | 64 | 128 | 256 | 512 | 1024 |
| PAPR (in dB) | 18.06 | 21.07 | 24.08 | 27.09 | 30.1 |

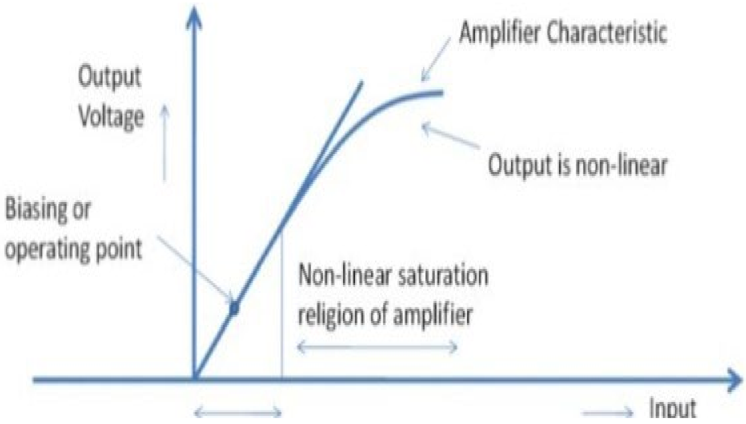


**Fig. 2 - Effect of PAPR on OFDM system**

As a result, in an OFDM system, PAPR could be quite high. Furthermore, as N, or the number of subcarriers, increases, the PAPR rises. In an OFDM system, the IFFT operation is principally responsible for the high PAPR shown in fig 2. A signal with a high peak value can be produced by adding data symbols across sub carriers [26]. For example, the PAPR at the output of an OFDM system with 512 sub carriers and BPSK modulation can reach 27 dB as shown in table1.

## 2.3 Effect of PAPR in OFDM System

Peak voltage value variations are particularly large in an OFDM system as compared to the average value, and the output voltage value is moved outside the linear range. Inter-Carrier-Interference (ICI) will arise in an OFDM system because to the high PAPR. Because of the high PAPR in the OFDM system, the RF power amplifier efficiency would suffer. The data transmission range in multi carrier systems will be reduced and spectral growth will be reduced if the transmitted power peak value is reduced for regulatory standards and application limits. If the system has a high PAPR value, the power amplifier will operate in the non-linear zone, which will reduce the battery lifetime. As a result, the benefits of multicarrier communication will be rolled out with a high PAPR value [27-29]. The signal is transmitted through the power amplifier in a practical OFDM system, but the peak strength of the power amplifier is limited. If the signal power exceeds the saturation point, the signal will be clipped. If clipping occurs in an OFDM system, the orthogonality property between sub carriers is destroyed, resulting in an increase in bit error rate.

Non-linear power amplifiers were necessary in practically all communication systems for longer-range data transmission, but the power amplifier had to operate in a greater linear range for improved efficiency. As a result, efficiency and linearity are mutually exclusive [30].

Because the signal amplitude is quantifiable in single-carrier modulation, the operating point measurement is precise. The signal amplitude changes with the data symbols in multi-carrier modulation systems like OFDM. As a result, variations in operating point will be observed, resulting in system distortion. At the receiver, this distortion acts as noise, and the signal constellation rotates as a result of the phase conversion. Cross talk is caused by out-of-band distortion of the subcarriers, as well as the orthogonality between subcarriers [31-34]. To determine the distortion induced by non-linearity, the signal must be measured to demonstrate its susceptibility to non-linearity.

The following aspects must be considered before selecting the appropriate PAPR reduction approach in a digital communication system. Increased transmit signal power, reduced PAPR capacity, increased Bit Error Rate at the receiver, data rate loss, computation complexity, and so on. The majority of approaches are ineffective for reducing PAPR with little coding, low complexity, no performance deterioration, and no symbol handshake between transmitter and receiver [37-39].

## 2.4 Complementary Cumulative Distribution Function (CCDF)

The complementary cumulative distribution function (CCDF) curve is used to define a digitally modulated signal's peak power statistic. In the temporal and frequency domains, most digitally modulated signals appear to be noise. Because of the non-linearity, statistical signal measurements are the best way to characterize the signals. The CCDF curves are quite beneficial when it comes to determining design parameters in digital communications systems. The CCDF curve shows how much time the waveform spends at or above a specific power level. The likelihood of a power level is calculated by measuring the amount of time the signal spends at or above that power level [27].

The Cumulative Distribution Function is a very important and commonly used function for determining the performance of a specific PAPR reduction strategy. CCDF curves are commonly used instead of CDF curves, and they describe the chance that the PAPR of a data block would exceed a specific threshold value [14]. The real and imaginary values of the signal become Gaussian distribution functions for a large number of sub carriers N in a multi carrier system, according to the definition of the central limit theorem, and the amplitude of the OFDM signal follows the Rayleigh distribution function.

The cumulative distribution for a multi-carrier OFDM signal is defined as:

$F(z) = 1 - e^{-Z}$

The probability that the PAPR is lower than some threshold level can be described as

$P\ (PAPR \le z) = F(z) = (1 - e^{-Z})^N$ The complementary cumulative distribution function (CCDF) of PAPR of an N carrier OFDM is defined as: $P\ (PAPR \ge z) = 1 - P(PAPR \le z) = 1 - F(z) = [1 - (1 - e^{-z})^N]$

**Algorithm 1** Algorithm for Calculation of PAPR:

1: Generate the message bits.
2: In order to generate code words message bits are encoded and modulated.
3: Apply the IFFT for the input symbols and generate samples
4: Compute the PAPR for the each OFDM sample
5: PAPR= Peak Power/Average Power
6: Compute the maximum power of the sample
7: Compute Mean or Average value of the sample
8: Compute the PAPR of the sample
9: Convert the PAPR into dB, i.e., 10*log10(PAPR)
10: Repeat the above steps for all samples
11: Find the CCDF (complementary cumulative distribution function) for PAPR values
12: Draw the Semi-Log Graph between PAPR and CCDF(PAPR). END

### 2.4.1. Advantages of OFDM

1. The spectrum can be efficiently utilized because of overlap property used
2. Eliminate ISI with the use of a cyclic prefix [26].
3. The symbols are recovered at the receiver by using proper channel coding.
4. It is possible to use maximum chances of decoding with low complexity

### 2.4.2. Disadvantages of OFDM

1. OFDM signal gives high PAPR and therefore it needs power amplifiers with larger dynamic range [28][29]
2. OFDM is more sensitive to carrier frequency offset than the single carrier systems [26].

## 3. Proposed Low-Complexity Schemes for Papr Reduction in OFDMA Systems

PAPR reduction techniques are:

1. PAPR reduction capability,
2. Power increase in transmit signal
3. BER increase at the receiver
4. Loss in data rate
5. Computational complexity increase

Other factors that can also consider into the account are transmit filter, digital to analog converter and the transmit power amplifier.

### 3.1 Signal Distortion Techniques

It reduces or clip the peak amplitudes of a signal at the expense of introducing a slight distortion of the spectrum of the signal.

1. Clipping and Filtering
2. Companding
3. Peak windowing
4. Peak cancellation
5. Peak Reduction Carrier
6. Envelope Scaling

### 3.2 Coding Techniques

Different coding sequences are used in the use of generating OFDM symbols.

1. Block Coding Techniques
2. Block Coding Scheme with Error Correction
3. Tone reservation
4. Tone injection
5. Active Constellation Extension
6. Interleaving Technique
7. Symbol-scrambling techniques

The main purpose of the technique is to scramble the input OFDM symbols by using number scrambled sequences. The output scrambled signal is equivalent to the smallest PAPR transmitted.

1. Partial Transmit Sequences
2. Selected Mapping

### 3.3 Signal Distortion Techniques

It reduces or clip the peak amplitudes of a signal at the expense of introducing a slight distortion of the spectrum of the signal.

### 3.3.1 Clipping and Filtering

While in OFDM signals, the large peaks appear rarely, thus clipping and filtering scheme is a very simple and straightforward way to reduce PAPR. This technique is accomplished in the time domain, where a soft limiter is used to control the amplitude of signals under a desirable level. The output signal of a soft limiter can be provided by,

$$x[n] = x[n] \qquad |x[n]| \leq At \tag{1}$$

$$_{Ate}j\varphi(x[n]) \qquad |x[n]| \geq At \tag{2}$$

where x[n] is the original signal, x[n] is the output after clipping, At is the clipping threshold, and $\varphi(x[n])$ is the phase of x[n] [2][3].

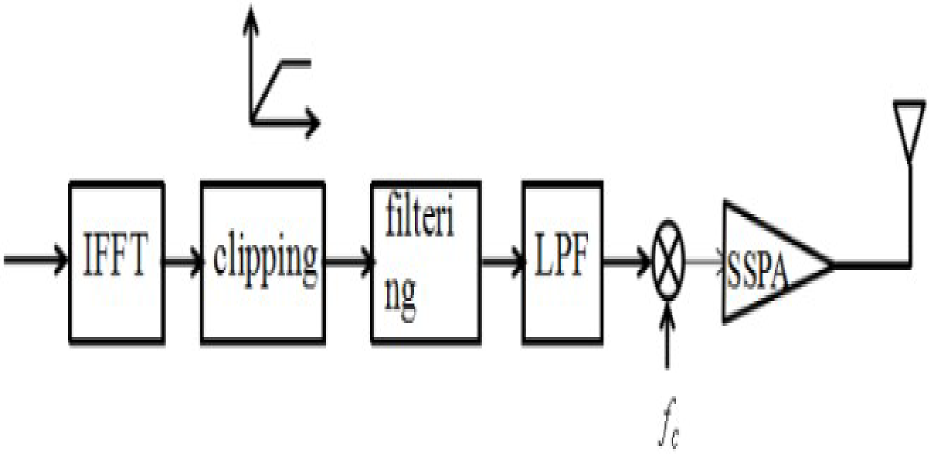


**Fig. 3 - Clipping and filtering**

Even though clipping is an efficient way to lower the PAPR value under a certain threshold, it may cause in-band distortion and out-of-band radiation. Also, the distortion produced by clipping can be considered as another kind of noise, which causes in BER degradation [2][3] shown in fig 3..

Filtering is a useful way to knock out the above problem in clipping. In filtering method, the clipped time-domain signals are transformed into the frequency-domain by Fast Fourier Transform (FFT). Then, the out-of-band signals are set to zero. The filtered signals are then again transformed into the time-domain by Inverse Fast Fourier Transform (IFFT). Even though filtering can decrease the out-of band radiation, it could affect some peak regrowth, so the signals after clipping and filtering could go beyond the clipping threshold. To resolve these problems, a repeated clipping and filtering may be used, which takes a number of iterations to reach a desired amplitude level, but the corresponding complexity improves as well. Some improved schemes have been proposed, which utilize the optimized filter H to filter out-of-band noise. Even though these schemes get better performance, there is a necessary to solve a convex optimization problem, which notably increases the computation complexity. Hence, these schemes have complications when they are employed in practice [2][3].

## 3.4 Companding

The nonlinear processing to decrease the Large PAPR in OFM system with the undesirable distortion produced by passing through the digital to analog converter (DAC) and HPA will be prevented. Companding technique compresses the signal with high peak and expands the signal with small amplitude. At the receiver side, the inverse action called decompanding is employed. Nevertheless, the companding technique makes signal distorted. So, some modified schemes have been proposed to compensate this drawback.Y. Wang, L-H. Wang and J-H. Ge proposed a nonlinear companding with variable companding parameters to attain good PAPR reduction with lower distortion. Also, it is suggested that the non-symmetric decompanding can increase BER performance for band limited OFDM systems. However, the BER degradation caused by pre-distortion is still not a negligible factor when a companding technique is employed for PAPR reduction.

## 3.5 Peak Windowing

Decreasing the PAPR by multiplying a larger signal peak by a Gaussian shaped window. The resultant spectrum is the convolution between the original OFDM spectrum and the spectrum of the applied window (cosine, Kaiser, and hamming functions). Observed that peak windowing gives considerable result independently from the number of subcarriers. The basic concept of peak windowing is to multiply the envelop of OFDM signal with a window function.

$$x^0e(t) = xe(t).f(t) \quad (3)$$

where $x_e(t) = |x(t)|$

$$f(t) = 1 - {}^{X}\alpha w(t - t^0) \quad (4)$$

w(t): is the window function

$t^0$: represents the position of a local maximum of the envelop $x_e(t)$.

*α:* attenuation constant

When the amplitude of the envelop amplitude signal go beyond a threshold, a window function is applied to the envelop of the orthogonal frequency multiplexing signal to remove the peak amplitude is shown in fig 4. The mathematical expression of the peak windowing is as follow:

$$w(t) = 0.5 - 0.5cos(2\pi t/T)0 \leq t \geq T \quad (5)$$

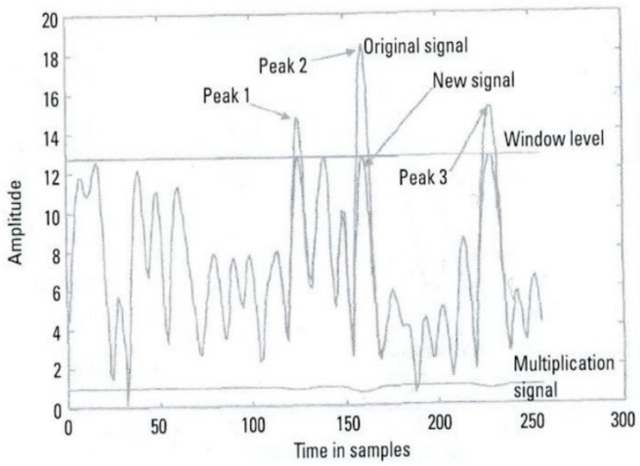


**Fig. 4 - Windowing an OFDM time signal**

## 3.6 Peak Cancellation

The essential idea of peak cancelation is to decrease the amplitude of the data samples when the magnitude go beyond a certain threshold [40-44]. A comparator can be used to check whether the OFDM symbol go beyond the threshold or not. In case the amplitude is beyond the threshold, the peak and the side lobes are scaled in way so that they maintain the certain threshold. fig 5 shows the block diagram of an OFDM transmitter with peak cancelation which is positioned next to the cyclic prefix (CP). And an example is shown in figure 14 which indicates the peak amplitude is reduced to 3 dB corresponding to the peak cancellation.

## 3.7 Peak Reduction Carrier

Tan and Wassell invented Peak Reduction Carrier, which uses data-bearing peak reduction carriers (PRCs) to reduce the effective PAPR in the OFDM system. A higher order modulation technique is used to represent a lower order modulation sign in this method. The PRC's amplitude and phase will be positioned within the constellation region indicating the data symbol that will be transferred using this approach. To use a PRC that uses a 16-PSK constellation to convey a QPSK data symbol, for example, the 16-phases of the 16-PSK constellations are separated into four areas to represent the QPSK symbol of the four different values.

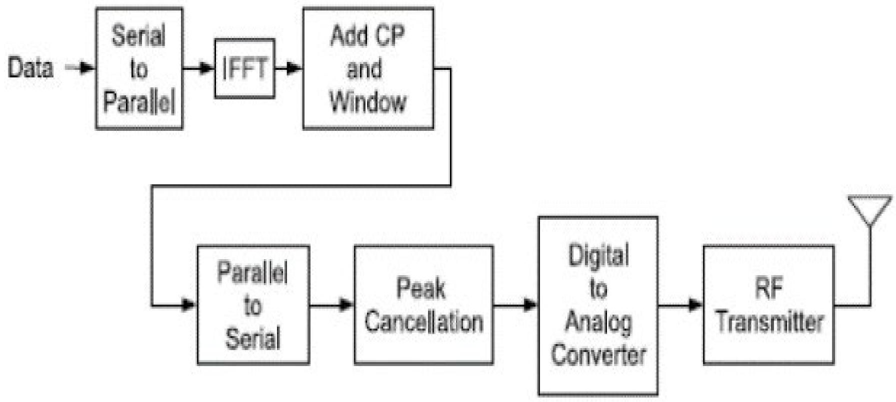


**Fig. 5 - PAPR reduction by peak cancellation**

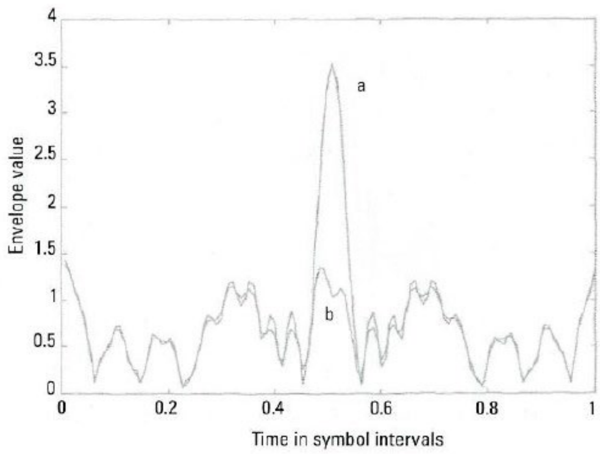


**Fig. 6 - Signal envelope of OFDM symbol**

## 3.8 Envelope Scaling

The Envelope Scaling method was recommended by Foomooljareon and Fernando. They proposed a new method for lowering the PAPR by scaling the input envelope of selected subcarriers before putting them via the Inverse Fast Fourier Transform (IFFT). To verify that the envelopes of all the subcarriers are comparable, they employed a QPSK modulation technique with 256 subcarriers. The primary idea behind this method is to scale the input envelopes of specific sub carriers to obtain the lowest amount of PAPR at the IFFT's output. As a result, the receiver in the system doesn't need any side data to decode the receiver sequence. This system has equal envelopes for all subcarriers, which is ideal for QPSK modulation. PAPR will be lowered by about 4 decibels. Finally, the system of single scaling factor and number of clusters equals number of sub carriers is recommended for this scheme shown in fig 6.

## 3.9 Coding Techniques

Special coding sequences are used for the purpose of generating the OFDM symbols with lower PAPR.

### 3.9.1 Block Coding Techniques

Signal scrambling is accomplished using block coding algorithms. M sequences, Shapiro-Rudin sequences, and Golay complementary sequences are utilised in block coding approaches to effectively lower the PAPR. Wilkinson and Jones devised the block coding technique in 1965 to reduce the peak to mean envelope power ratio of multicarrier communication systems. The main point is that by block coding the data, PAPR can be reduced. To reduce the PAPR, block coding techniques employ three stages of development. For any number of carriers, any M-ary phase modulation scheme, and any coding rate, the first stage will collect sufficient sets of code words [45-48]. The collecting of the sets of data will be the focus of the second stage. The third stage is concerned with the possibility of error deduction and rectification. The collecting of sets of code words can be done in a variety of ways. Because it necessitates extreme calculation, this method is easy and accurate for short codes. Natural algorithms are essentially advanced search strategies. It's used to keep track of lengthy code terms. When the frame size is larger, the code words are selected from searches for encoding and decoding using a look up table or combinatorial logic leveraging the mathematical structure of the codes minimization. The lengthy information sequence will be broken into multiple sub blocks for higher PAPR reduction, and all sub blocks will be encoded utilizing System on a Programmable Chip (SOPC). There are a lot of places where odd parity checking bits are inserted into each frame to reduce the PAPR. The redundant bit location optimized sub-block coding (RBLO-SBC) enhances these areas for even greater PAPR reduction. Redundant COSBC (combination optimized sub-block coding scheme) improves the combination of coded sub blocks by using two coding methods to represent the same information source instead of one [49].

### 3.9.2 Block Coding Scheme with Error Correction

Ahn implemented the Block coding scheme with Error Correction and suggested a novel block coding for lowering the peak to average power ratio (PAPR) in an OFDM system. Error correction is possible with block coding. The OFDM symbol is reduced in this block coding method by picking only code words with lower PAPR. The method's major goal is to advise that block codes be appropriately designed, which will not only reduce PAPR but also improve error repair capability. A k bit data block is encoded by a (n, k) block coding using the generator matrix 'G' in the system's transmitter. The Block coding scheme with Error Correction was implemented by Ahn and recommended a new block coding for the decrease of peak to average power ratio (PAPR) of an OFDM system. Block coding have the error correction capability. In this block coding method, the OFDM symbol is decreased by selecting only those code words with lesser PAPR. The main object of the method is suggested that properly design the block codes and those are not only minimizing the PAPR, but also gives the better error correction capability. With the use of generator matrix 'G' in the transmitter of the system, a k bit data block is encoded by a (n, k) block code[50]. To generate the encoded output x=a, use the phase rotator vector b. (mod 2). Create an accurate generator matrix and phase rotator vector for the OFDM system that will produce the lowest PAPR, and then examine all 2n codes and choose only 2k codes to get the lowest PAPR in the OFDM system. and following that, the generator matrix 'G' and phase rotator vector 'b' are created, which are used to translate these symbol combinations to the input data vector 'a'. The receiver system performs the transmitters in reverse tasks. The parity check matrix 'H' is calculated from the generator matrix 'G,' with the exception that the effect of the phase rotator vector b is eliminated before the syndromes are calculated.

### 3.9.3 Tone Reservation

TR is the distortion-less PAPR reduction technique suggested by Tellado. The term" Tone" represents the subcarrier because this scheme is initially developed for a DSL system and subcarriers are called tones in the DSL system. The TR scheme utilizes a part of tones which is called peak reduction tone (PRT) to reduce the PAPR. In most cases, PRT do not contain any information data and they are added to original OFDM signals to generate new signals with lower PAPR. There are two types of TR scheme: clipping based TR and gradient based TR [20][21]. The PAPR reduction performance of TR is based on the PRT set and clipping threshold, which is a NP-hard problem. The kernel p should be optimized over all the possible discrete sets of R, so, it cannot be solved for practical subcarrier numbers. However, in this section, only the conventional TR scheme is studied [20][21].

### 3.9.4 Tone Injection

Although TR schemes achieve efficient PAPR reduction performance, Peak Reduction Tone (PRT) could waste valuable subcarriers, which significantly decrease the data rate. The tone injection (TI) scheme can be used to reduce PAPR without data rate reduction. In the TI scheme, the tones are overlapped with data tones. The key idea of TI is to enhance the constellation size so that each of the point in the original constellation will be mapped into several equivalent points in the new expanded constellation where the extra degrees of freedom can be achieved to reduce PAPR. In other word, the time domain PAPR reduced signals can be generated from the different combinations of the overlapped data signals and peak reduction signals [9].

### 3.9.5 Active Constellation Extension

Active constellation extension (ACE) is to pre-distort the input symbols before IFFT to decrease the PAPR. In the ACE scheme, in order to keep the minimum distance of the constellation unchanged, only the outer constellation symbols can be predistorted. In this manner, there is no BER degradation at the receiving side. In the ACE method, the points in the side of the constellation are moved along the half-line in the outer direction, while points in the corner of the constellation will be moved in larger quadrant area. The benefits of ACE scheme are no data loss and no SI, but, in order to maintain the minimum distance, the ACE may cause peak regrowth, which increases the average power and the amount of iterations [18][19]. In fact, TI and ACE schemes are normally revised versions of TR. Both these two schemes need to change the size of constellation. In other words, adding extra signals with more power into the original constellation of the OFDM signals increases the transmitting power. Additionally, compared with TR, ACE and TI need to solve a more complex nonlinear constrained optimization problem, which makes these two schemes unpopular [18][19].

### 3.9.6 Interleaving Technique

Jayalath and Tellambura devised an interleaving strategy to reduce the peak to average power ratio of an OFDM transmission. The PAPR should be minimized by using a data randomization strategy. If a long correlation pattern is broken down, the concept that highly correlated data structures have higher PAPR can be disproved. In addition, an additive strategy for reducing complexity is proposed. The basic concept of adaptive interleaving is to define a terminating threshold at the start. Instead of seeking each interleaved sequence, the PAPR value falls below the threshold. The adaptive interleaving (AL) will be forced to look for all interleaved sequences if the minimal threshold is met. The key benefit of this strategy is that it is less complicated than the PTS technique while achieving similar results.

### 3.9.7 Symbol-scrambling Techniques

The main purpose of the technique is to scramble the input OFDM symbols by using number scrambled sequences. The output scrambled signal is equivalent to the smallest PAPR transmitted.

### 3.10. Partial Transmit Sequence

The input data block X is partitioned into P disjoint sub blocks Xp = [Xp,0, Xp,1... Xp,N-1]T, p=1,2... P, and the partitioned sub blocks are concatenated to lower the PAPR in the time domain using the PTS technique shown in fig 7. Taking the IFFT of length Sp on Xp concatenated with (S – 1) M zeros yield the S times oversampled time domain signal of Xp, p=1...P. The incomplete transmit sequences for transmission are what they're termed. These are called the partial transmit sequences for transmission. Complex phase factors, $ap = e^{j\varphi p}$, p=1,2 ... P, are introduced to combine the PTSs. The set of phase factors is denoted a vector a= [a1, a2 ... aM]$^T$ [15]-[17]. The time domain signal after mixing is given by:

$$x^0(a) = \sum_{p=1}^{P} apxp \qquad (6)$$

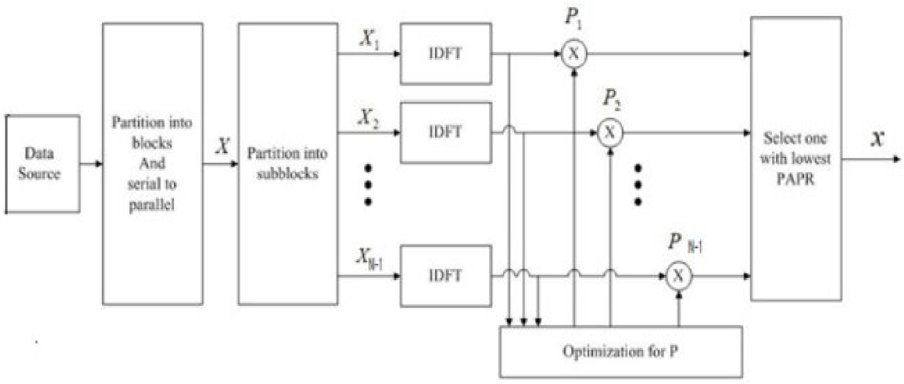


**Fig. 7 - PTS technique**

Then, P different candidate PTS OFDM signals are compared, and the system selects one that has the minimum PAPR for transmission, as $p = arg(minPAPR(x^0(a)))1 \leq m \leq M$ In order to recover the input data, the receivers needs to know the index of p. In PTS conventional cases, the system needs to do thorough search to find the best phase rotation factors combination to reduce the PAPR, for example, if there are 4 subblocks, the system has to find the best phase rotation factors from 2(4-1) = 8 candidate sequences. In PTS scheme the performance and the computational complexity is led by the number of subblocks and candidate sequences.

Hence, the conventional PTS scheme will suffer with high computational complexity in order to get an efficient PAPR reduction performance [15]-[17].

## 3.11 Selected Mapping

The fundamental goal of this strategy is to produce statistically independent sequences at the transmitter end that represent the same information as the original information, and then choose the Low PAPR value block among them for transmission.

The main difference between SLM and PTS is that in the PTS scheme the actual data are rotated by phase rotation factors in the subgroups after that

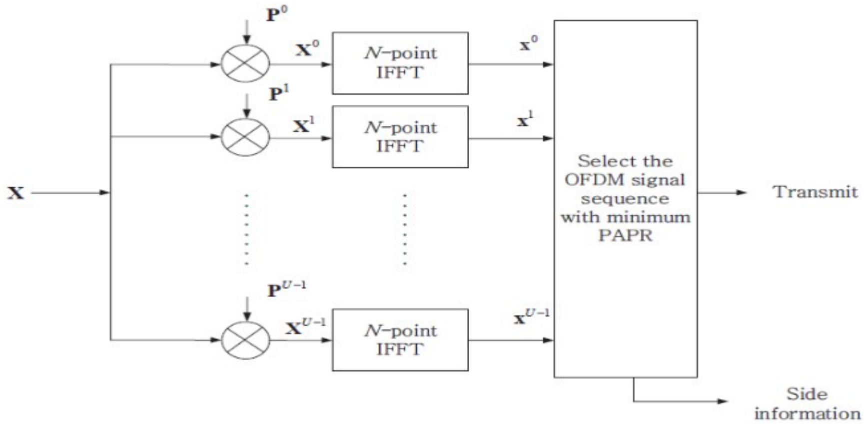


**Fig. 8 - The conventional SLM method**

Inverse Fast Fourier Transform (IFFT) operation will be performed while in SLM the original data are rotated one by one before the IFFT operation [6][7]. Even though both PTS and SLM are distortion-less PAPR reduction schemes, SLM has more advantages than PTS. PTS is lower computational complexity technique. However, PTS shows advantages on complexity only when less than a specific number of PTS subblocks are used. If the computational complexity of SLM and PTS are fixed, SLM scheme can outperform than PTS scheme in terms of PAPR performance since SLM can produce multiple time-domain signals that are independent, while the alternative signals generated by PTS are interdependent [6][7] shown in fig 8.

Table.2. gives a brief comparison among different kind of PAPR reduction schemes with the respect of PAPR reduction capability (PRC), average power increase (API), BER depredation (BER), data rate loss (DRL), out-of-band radiation (OBR) and computational complexity (CC).

**Table 2 - Different PAPR reduction methods**

| PAPR Reduction Method | PRC | API | BER | DRL | CC | OBR |
|---|---|---|---|---|---|---|
| Clipping and Filtering | Good | N | Y | N | Low | Y |
| Companding | Good | N | Y | N | Med | Y |
| Coding | Good | N | N | Y | High | N |
| PTS | Good | N | N | Y | High | N |
| SLM | Good | N | N | Y | High | N |
| TR | Good | N | N | Y | High | N |
| TI | Good | Y | N | N | High | N |

## 3.10 Novel Low-Complexity Scheme for PAPR Reduction in OFDMA Systems

Unlike traditional SLM techniques, which necessitate a large number of IFFTs, the suggested scheme only necessitates one IFFT. The architecture of the investigated PAPR reduction approach is depicted in Figure 9. The time-domain signal is processed by M 1 Candidate Signal Generating Blocks (CSGBs) after the OFDMA and IFFT processes, generating a total of M candidate signals, one of which is the original time-domain transmitted signal. It should be noted that at the receiver end, decoding proposals necessitates a total of log2M side information bits. Figure 10 shows how each CSGB is built by merging a number of various signals, including the initial time-domain sent signal. and the original signal's many cyclic shift equivalents multiplied by various complex values.

Unlike standard SLM methods, which necessitate many IFFTs, the proposed scheme only necessitates one. fig 9 depicts the architecture of the PAPR reduction scheme that was studied. Following the OFDMA modulation and IFFT operations, the time-domain signal is processed by M-1 Candidate Signal Generating Blocks (CSGBs), yielding M candidate signals, one of which is the original time-domain transmitted signal. Decoding proposals at the receiver end necessitates a total of log2M side information bits. As a result, the uth user's mth candidate signal takes the following general form: *xu,m* = *xu* +*am,*1. *ejθm,*1*xuPm,*1 +*am,*2*ejθm,*1*xuPm,*2 +*am,*3*ejθm,*1*xuPm,*3 (7)
where $a_{m,1}$, $a_{m,2}$, $a_{m,3}$ are non-negative real numbers, $\theta_{m,1}, \theta_{m,2}, \theta_{m,3} \epsilon (0, 2\pi), x_p$

denotes the p^th^ cyclic shift of $x_u$, and $P_{m,1}, P_{m,2}, P_{m,3}$ ϵ 0, 1....LN-1. It should be observed that anyone, two, or all three components of the set $a_{m,1}$, $a_{m,2}$, $a_{m,3}$ can be zero. To put it another way, each candidate signal is made up of two, three, or four signals, one of which is the original time-domain sent signal. The kth sub-carrier of the m^th^ candidate signal in the frequency domain can be expressed as: Taking the DFT of both sides of Eq. (5), the kth sub-carrier of the m^th^ candidate signal can be represented as:

$$X_{u,m}[k] = G_m[k].X_u[k] \quad (8)$$

## 4. Analysis of Computational Complexity

The proposed scheme's candidate signals are generated in the time domain and are made up of the original transmitted signal and its cyclic shift equivalents. The phase rotations of the corresponding frequency-domain signal are equivalent to the cyclic shift versions of the time-domain signal. As a result, the suggested strategy can be classified as a modified SLM. To create M candidate signals, the classic SLM technique takes a total of M IFFT operations, with each operation requiring (N/2) log2(N) complex multiplications and (N) log2(N) complex additions. However, the suggested technique only requires one IFFT operation and (N/2) log2(N) complex multiplications and (N) log2(N) complex additions, resulting in a significant reduction in computational cost.

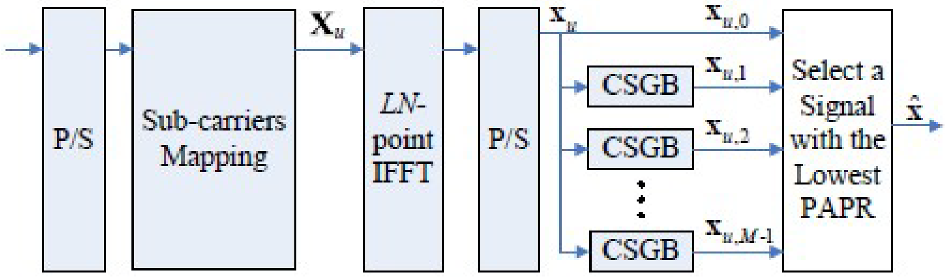


**Fig. 9 - Investigated PAPR reduction method**

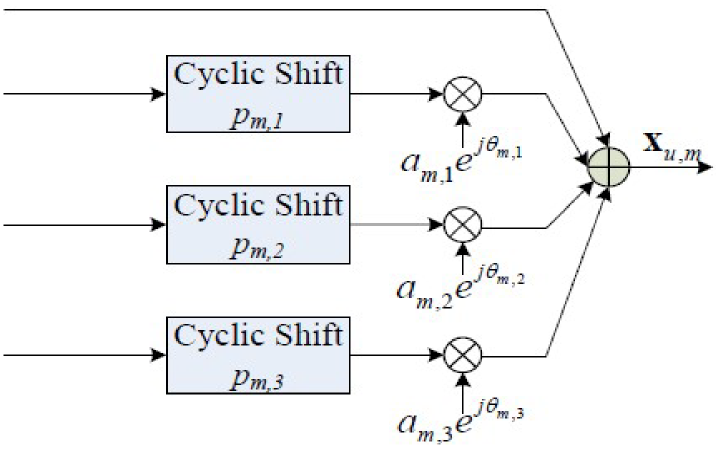


**Fig. 10 - CSGB in the investigated PAPR reduction**

The proposed scheme's computational complexity ratio (CCR) versus the standard SLM technique is defined and shown in fig. 9 and fig. 10. The computational complexity ratio (CCR) of the proposed scheme over the classic SLM scheme is defined as follows to further show the percentage for the amount of complex multiplications and additions required in the proposed scheme compared to the existing SLM and is shown in table 3.

**Table 3 - Computational complexity of various schemes**

| **PAPR Reduction** | Number of Complex Multiplications | Number of Complex Additions |
|---|---|---|
| Traditional SLM | (MN/2) log2(N) | MN log2N |
| Proposed SLM | (N/2) log2(N) | N log2(N) |

**Table 4 - Computational complexity of various schemes with m constant**

| PAPR Reduction Method | No. of Complex Multiplications | | | No. of Complex Multiplications | | |
|---|---|---|---|---|---|---|
| | M = 32 | | | | | |
| | N=256 | N=512 | N=1024 | N=256 | N=512 | N=1024 |
| Traditional SLM Scheme | 32768 | 73728 | 163840 | 65536 | 147456 | 327680 |
| Proposed SLM Scheme | 1024 | 2304 | 5120 | 2048 | 4608 | 10240 |
| CCR | 3.125 | 3.125 | 3.125 | 3.125 | 3.125 | 3.125 |

**Table 5 - Computational complexity of various methods with n constant**

| PAPR Reduction Method | No. of Complex Multiplications | | | No. of Complex Multiplications | | |
|---|---|---|---|---|---|---|
| | N=1024 | | | | | |
| | M=8 | M=16 | M=32 | M=8 | M=16 | M=32 |
| Traditional SLM Scheme | 40960 | 81920 | 163840 | 81920 | 163840 | 327680 |
| Proposed SLM Scheme | 5120 | 5120 | 5120 | 10240 | 10240 | 10240 |
| CCR | 12.5 | 6.25 | 3.125 | 12.5 | 6.25 | 3.125 |

scheme:

$$CCR = \frac{Complexity of Proposed Scheme}{Complexity of Tradinal SLM} * 100 \quad (9)$$

The computational difficulties of the classic SLM scheme and the modified Proposed Scheme for OFDMA systems are summarized in table 4 and table 5. It should be noted that the computational complexity of the proposed scheme can be further reduced by increasing the number of IFFTs.

## 5. Simulation Results

In this paper OFDM transmitter is implemented using M-array QAM for different orders of FFTs and IFFTs. The following figure indicates, the CCDF plot comparing the performance of PAPR in OFDM without SLM, with SLM and modified SLM using 4-QAM modulation. Fig. 11 plot shows that the performance in OFDM is better in modified SLM compared to conventional SLM using 4-QAM. Fig. 11 demonstrates the modified SLM which provides better PAPR performance over uncoded and conventional SLM. Fig. 11 demonstrates 6 dB PAPR improvement over conventional OFDM at BER $10^2$ and is shown in table 6.

**Table 6 - The performance of PAPR in OFDM without SLM, with SLM and modified SLM using 4-QAM modulation**

| Modulation | OFDM 4-QAM | SLM 4-QAM | Modified SLM 4-QAM |
|---|---|---|---|
| No of Input Symbols | 49152 | 49152 | 49152 |
| No of Symbol Blocks | 24576 | 24576 | 24576 |
| IFFT Size | 128 | 128 | 128 |
| PAPR (in dB) | 10.2 | 6.6 | 3.9 |

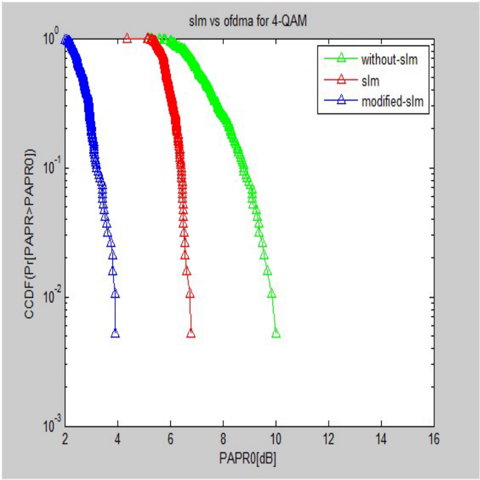


**Fig. 11 - PAPR improvement in modified SLM over conventional OFDM and SLM for 4-QAM**

Fig. 12 indicates, the CCDF plot comparing the performance of PAPR in OFDM without SLM, with SLM and modified SLM using 8-QAM modulation. The fig 12. plot shows that the performance in OFDM is better in modified SLM compared to conventional SLM using 8-QAM shown in table7. The fig 12. demonstrates the modified SLM which provides better PAPR performance over uncoded and conventional SLM. Fig. 12 demonstrates 4 dB PAPR improvement over conventional OFDM at BER $10^2$.

**Table 7 - The performance of PAPR in OFDM without SLM, with SLM and modified SLM using 8-QAM modulation**

| Modulation | OFDM 8-QAM | SLM 8-QAM | Modified SLM 8-QAM |
|---|---|---|---|
| No of Input Symbols | 49152 | 49152 | 49152 |
| No of Symbol Blocks | 16384 | 16384 | 16384 |
| IFFT Size | 128 | 128 | 128 |
| PAPR (in dB) | 10.2 | 6.5 | 6.3 |

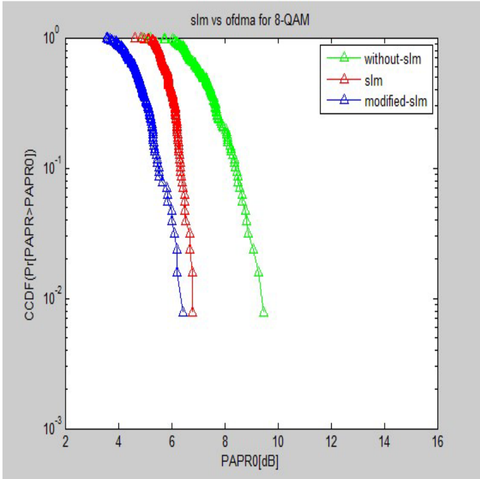


**Fig. 12 - PAPR improvement in modified SLM over conventional OFDM and SLM for 8-QAM**

The following figure indicates, the CCDF plot comparing the performance of PAPR in OFDM without SLM, with SLM and modified SLM using 64-QAM modulation. The above plot shows that the performance in OFDM is better in modified SLM compared to conventional SLM using 64-QAM. The fig 13 demonstrates the modified SLM which provides better PAPR performance over uncoded and conventional SLM shown in table8.

**Table 8 - The performance of papr in OFDM without SLM, with SLM and modified SLM using 64-QAM modulation**

| Modulation | OFDM 64-QAM | SLM 64-QAM | Modified SLM 64-AM |
|---|---|---|---|
| No of Input Symbols | 49152 | 49152 | 49152 |
| No of Symbol Blocks | 8192 | 8192 | 8192 |
| IFFT Size | 128 | 128 | 128 |
| PAPR (in dB) | 8.9 | 6.3 | 6.2 |

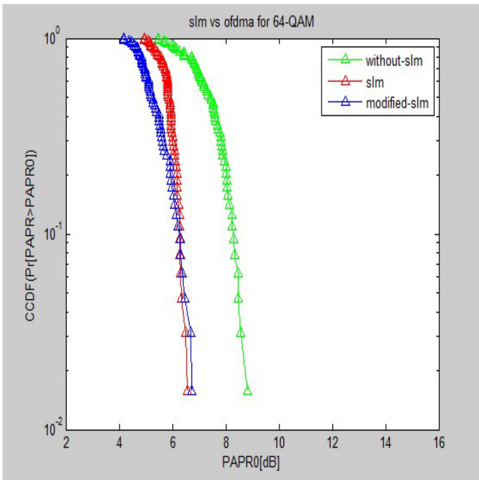


**Fig. 13 - The performance of PAPR in OFDM without SLM, with SLM and Modified SLM using 64-QAM modulation**

The main advantage of modified SLM is that it greatly reduces computational complexity over conventional SLM as it requires only one IFFT irrespective of number of IFFTs in conventional SLM.

## 6. Conclusion

In this work OFDM transmitter is implemented with SLM. In SLM OFDM the PAPR improvement of modified SLM is similar to that of conventional SLM but modified SLM greatly reduces computational complexity over conventional SLM as it requires single IFFT irrespective of number of IFFTs used in conventional SLM corresponding author on reasonable request.

## References


1. IEEE Standards Association. (2012). IEEE Standard for local and metropolitan area networks—Part 15.6: Wireless body area networks. *IEEE std*, *802*(6), 2012.
2. Li,X.(1998) and JL Cimini (1998). Effect of clipping and filtering on the performance of OFDM.IEEE Com.
3. Wulich, D., & Goldfeld, L. (1999). Reduction of peak factor in orthogonal multicarrier modulation by amplitude limiting and coding. *IEEE transactions on communications*, *47*(1), 18-21.
4. Sharif, M., Tarokh, V., & Hassibi, B. (2009). Peak power reduction of OFDM signals with sign adjustment. *IEEE Transactions on Communications*, *57*(7), 2160-2166.
5. Bauml, R. W., Fischer, R. F., & Huber, J. B. (1996). Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping. *Electronics letters*, *32*(22), 2056-2057.
6. Lu, G., Wu, P., & Aronsson, D. (2007). Peak-to-average power ratio reduction in OFDM using cyclically shifted phase sequences. *IET communications*, *1*(6), 1146-1151.
7. Ghassemi, A., & Gulliver, T. A. (2008). Partial selective mapping OFDM with low complexity IFFTs. *IEEE Communications Letters*, *12*(1), 4-6.
8. Le Goff, S. Y., Khoo, B. K., Tsimenidis, C. C., & Sharif, B. S. (2008). A novel selected mapping technique for PAPR reduction in OFDM systems. *IEEE Transactions on Communications*, *56*(11), 1775-1779.
9. Le Goff, S. Y., Al-Samahi, S. S., Khoo, B. K., Tsimenidis, C. C., & Sharif, B. S. (2009). Selected mapping without side information for PAPR reduction in OFDM. *IEEE Transactions on Wireless Communications*, *8*(7), 3320-3325.
10. Jeon, H. B., No, J. S., & Shin, D. J. (2011). A low-complexity SLM scheme using additive mapping sequences for PAPR reduction of OFDM signals. *IEEE Transactions on Broadcasting*, *57*(4), 866-875.
11. Yang, L., Soo, K. K., Siu, Y. M., & Li, S. Q. (2008). A low complexity selected mapping scheme by use of time domain sequence superposition technique for PAPR reduction in OFDM system. *IEEE transactions on Broadcasting*, *54*(4), 821-824.
12. Wang, C. L., & Ouyang, Y. (2005). Low-complexity selected mapping schemes for peak-to-average power ratio reduction in OFDM systems. *IEEE Transactions on signal processing*, *53*(12), 4652-4660.
13. Li, C. P., Wang, S. H., & Wang, C. L. (2010). Novel low-complexity SLM schemes for PAPR reduction in OFDM systems. *IEEE Transactions on Signal Processing*, *58*(5), 2916-2921.
14. Wang, S. H., & Li, C. P. (2009). A low-complexity PAPR reduction scheme for SFBC MIMO-OFDM systems. *IEEE Signal Processing Letters*, *16*(11), 941-944.
15. Ghassemi, A., & Gulliver, T. A. (2008). A low-complexity PTS-based radix FFT method for PAPR reduction in OFDM systems. *IEEE Transactions on Signal Processing*, *56*(3), 1161-1166.
16. Tsai, Y. R., & Huang, S. J. (2008). PTS with non-uniform phase factors for PAPR reduction in OFDM systems. *IEEE Communications letters*, *12*(1), 20-22.
17. Krongold, B. S., & Jones, D. L. (2003). PAR reduction in OFDM via active constellation extension. *IEEE Transactions on broadcasting*, *49*(3), 258-268.
18. Bae, K., Andrews, J. G., & Powers, E. J. (2009). Adaptive active constellation extension algorithm for peak-to-average ratio reduction in OFDM. *IEEE Communications Letters*, *14*(1), 39-41.
19. Behravan, A., & Eriksson, T. (2009). Tone reservation to reduce the envelope fluctuations of multicarrier signals. *IEEE Transactions on Wireless Communications*, *8*(5), 2417-2423.
20. Behravan, A., & Eriksson, T. (2009). Tone reservation to reduce the envelope fluctuations of multicarrier signals. *IEEE Transactions on Wireless Communications*, *8*(5), 2417-2423.
21. Krongold, B. S., & Jones, D. L. (2004). An active-set approach for OFDM PAR reduction via tone reservation. *IEEE transactions on signal processing*, *52*(2), 495-509.
22. Wunder, G., & Boche, H. (2003). Peak value estimation of bandlimited signals from their samples, noise enhancement, and a local characterization in the neighborhood of an extremum. *IEEE Transactions on Signal Processing*, *51*(3), 771-780.

23. Litsyn, S., & Yudin, A. (2005). Discrete and continuous maxima in multicarrier communication. *IEEE Transactions on Information theory*, *51*(3), 919-928.
24. Zhou, G. T., & Peng, L. (2006). Optimality condition for selected mapping in OFDM. *IEEE Transactions on Signal Processing*, *54*(8), 3159-3165.
25. Solyman, A. A., Attar, H., Khosravi, M. R., & Koyuncu, B. (2020). MIMO-OFDM/OCDM low-complexity equalization under a doubly dispersive channel in wireless sensor networks. *International Journal of Distributed Sensor Networks*, *16*(6), 1550147720912950.
26. Trivedi, V. K., Ramadan, K., Kumar, P., Dessouky, M. I., & Abd El-Samie, F. E. (2019). Enhanced OFDM-NOMA for next generation wireless communication: a study of PAPR reduction and sensitivity to CFO and estimation errors. *AEU-International Journal of Electronics and Communications*, *102*, 9-24.
27. Liu, C. S. (2018). Solving singular convection–diffusion equation by exponentially-fitted trial functions and adjoint Trefftz test functions. *Journal of King Saud University-Science*, *30*(1), 100-105.
28. Lu, B., & Wang, X. (2000, November). Space-time code design in OFDM systems. In *Globecom'00-IEEE. Global Telecommunications Conference. Conference Record (Cat. No. 00CH37137)* (Vol. 2, pp. 1000-1004). IEEE.
29. Bassem, B. J. A., Slaheddine, J., & Ammar, B. (2007, March). A PAPR reduction method for STBC MIMO-OFDM systems using SLM in combination with subband permutation. In *2007 Third International Conference on Wireless and Mobile Communications (ICWMC'07)* (pp. 88-88). IEEE.
30. Tiwari, B. K., & Dwivedi, C. K. Minimization of peak to average power ratio by selective mapping technique in OFDM environment.
31. Sharma, P. K., & Basu, A. (2010, October). Performance analysis of peak-to-average power ratio reduction techniques for wireless communication using OFDM signals. In *2010 International Conference on Advances in Recent Technologies in Communication and Computing* (pp. 89-95). IEEE.
32. Dewangan, L., Singh, M., & Dewangan, N. (2012). A Survey of PAPR Reduction Techniques in LTE-OFDM System. In *International Journal of Recent Technology and Engineering (IJRTE)* (Vol. 1, No. 5).
33. Jha, A., Sher, M. S. M., Alam, S. S., Hasan, M. T., & Rahman, M. M. (2009, November). Reduction of peak to average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM): A novel approach based on clipping and amplification. In *2009 Fourth International Conference on Computer Sciences and Convergence Information Technology* (pp. 921-926). IEEE.
34. Wang, Z., & Chen, S. (2014). Reduction PAPR of OFDM signals by combining grouped DCT precoding with PTS. *Journal of Signal and Information Processing*, *5*(04), 135.
35. NagaJyothi, G., & SriDevi, S. (2017, March). Distributed arithmetic architectures for fir filters-a comparative review. In *2017 International conference on wireless communications, signal processing and networking (WiSPNET)* (pp. 2684-2690). IEEE.
36. Jyothi, G. N., Sanapala, K., & Vijayalakshmi, A. (2020). ASIC implementation of distributed arithmetic based FIR filter using RNS for high speed DSP systems. *International Journal of Speech Technology*, *23*(2), 259-264.
37. Karthick Raghunath, K. M., Koti, M. S., Sivakami, R., Vinoth Kumar, V., NagaJyothi, G., & Muthukumaran, V. (2022). Utilization of IoT-assisted computational strategies in wireless sensor networks for smart infrastructure management. *International Journal of System Assurance Engineering and Management*, 1-7.
38. Jyothi, G. N., Gorantla, A., & Kudithi, T. (2020). Asic implementation of linear equalizer using adaptive fir filter. *International Journal of e-Collaboration (IJeC)*, *16*(4), 59-71.
39. Stuber, G. L., Barry, J. R., Mclaughlin, S. W., Li, Y., Ingram, M. A., & Pratt, T. G. (2004). Broadband MIMO-OFDM wireless communications. *Proceedings of the IEEE*, *92*(2), 271-294.
40. Schmidt, K. U. (2007). Complementary sets, generalized Reed–Muller codes, and power control for OFDM. *IEEE Transactions on Information Theory*, *53*(2), 808-814.
41. Daoud, O., & Alani, O. (2009). Reducing the PAPR by utilisation of the LDPC code. *IET communications*, *3*(4), 520-529.
42. Krongold, B. S., & Jones, D. L. (2003). PAR reduction in OFDM via active constellation extension. *IEEE Transactions on broadcasting*, *49*(3), 258-268.
43. Tellado, J. (1999). Peak-to-average power reduction for multicarrier modulation. *Ph. D. thesis*.
44. Guel, D., Palicot, J., & Louët, Y. (2010). Tone reservation technique based on geometric method for orthogonal frequency division multiplexing peak-to-average power ratio reduction. *IET communications*, *4*(17), 2065-2073.
45. Müller, S. H., Bäuml, R. W., Fischer, R. F., & Huber, J. B. (1997, January). OFDM with reduced peak-to-average power ratio by multiple signal representation. In *Annales des télécommunications* (Vol. 52, No. 1, pp. 58-67). Springer-Verlag.

46. Mobasher, A., & Khandani, A. K. (2006). Integer-based constellation-shaping method for PAPR reduction in OFDM systems. *IEEE Transactions on Communications*, *54*(1), 119-127.
47. Sahraoui, L., Messadeg, D., & Doghmane, N. (2013). Analyses and performance of techniques PAPR reduction for STBC MIMO-OFDM system in (4G) wireless communication. *arXiv preprint arXiv:1311.3638*.
48. Alsusa, E., & Yang, L. (2008). Redundancy-free and BER-maintained selective mapping with partial phase-randomising sequences for peak-to-average power ratio reduction in OFDM systems. *IET communications*, *2*(1), 66-74.
49. Le Goff, S. Y., Al-Samahi, S. S., Khoo, B. K., Tsimenidis, C. C., & Sharif, B. S. (2009). Selected mapping without side information for PAPR reduction in OFDM. *IEEE Transactions on Wireless Communications*, *8*(7), 3320-3325.
50. Wang, C. L., & Ouyang, Y. (2005). Low-complexity selected mapping schemes for peak-to-average power ratio reduction in OFDM systems. *IEEE Transactions on signal processing*, *53*(12), 4652-4660.